

# **High Frequency Acoustical Propagation and Scattering in Coastal Waters**

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## **LONG-TERM GOALS**

To study the physical processes controlling the propagation of high frequency acoustical signals. Of particular interest is the relationship between bubble distributions, surface gravity waves and turbulence and their effects on sound propagation as it affects underwater communication. A second long-term goal is to model these processes to improve our understanding and to enhance the predictive capabilities.

## **OBJECTIVES**

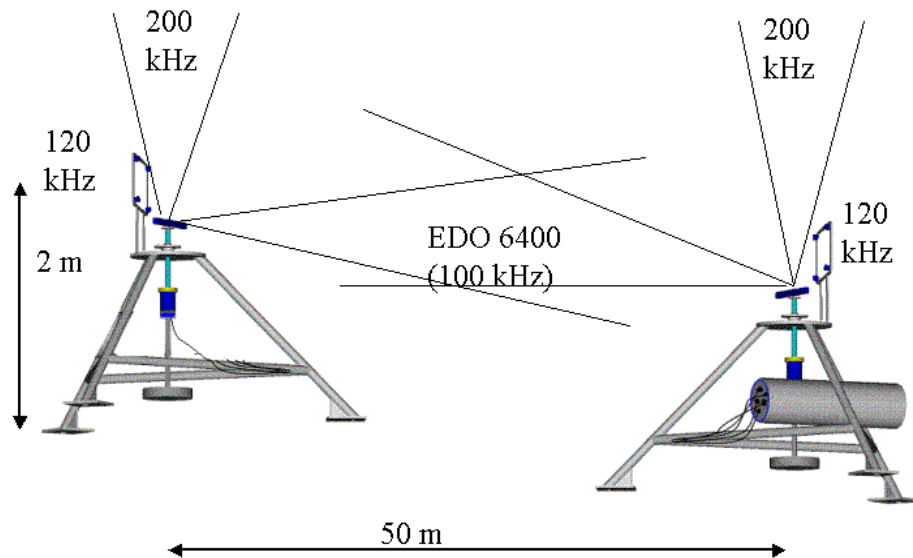
Our objectives are (1) to develop new techniques and approaches for high frequency acoustical propagation experiments in environments with dense bubble distributions and significant turbulence; (2) to carry out such experiments; (3) to model sound propagation in these environments; and (4) to interpret the results in terms of appropriate acoustic models.

## **APPROACH**

Our approach to studies of high frequency propagation in bubbly water near the ocean surface includes observational and model analysis of forward and back-scattered sound as well as analysis of the naturally occurring ambient noise field. Following the failed mooring and loss of instruments that occurred in the first field attempt (SPACE02) at the Martha's Vineyard Coastal Observatory experiment and further delays associated with the permitting process, our efforts in the past year have focused on resolving technical issues with the high frequency propagation apparatus and optimizing analysis software, in preparation for the SPACE 08 experiment to be carried out in October 2008. The project has been substantially revised and is to be carried out with MURI funding under the Acoustic Communications topic.

In 2007-2008, a series of tests were carried out in Narragansett Bay over a relatively short path of 50m. The new instrumentation includes high-frequency (100kHz) acoustical backscatter in both vertical and slant mode operation to investigate dense bubble clouds in the surf zone and their link to wave and bottom induced turbulence. The acoustic system incorporates four transducers with adjustable positions at each end of a bistatic array, allowing separation of path averaged sound speed and along-path velocity components. The transducers can be arranged horizontally or in a rectangular configuration at each end of the bistatic array as shown in Figure 1.

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**Figure 1. Sketch of the propagation instrumentation to be used in SACE 02 and tested in Narragansett Bay. Four transducers at each end of the path are used to acquire reciprocal transmission data, simultaneously with backscatter sonar's oriented vertically and horizontally.**

The underlying concept of this approach is that if we can both measure essential characteristics of the bubble distribution simultaneously with bubble induced changes to the acoustic propagation, we can test propagation models that incorporate representations of the bubble clouds. It should be emphasized that the bubble distributions along the path will have to be inferred from spot measurements of the bubble size distribution using acoustical resonators and estimates of bubble penetration depth from sonars. Bubble populations inferred from the sonars can be verified with *in situ* sensors (i.e. Farmer Booth & Vagle, 1998 and 2005) and have proven effective at measuring the acoustical environment in inshore waters.

The propagation measurements and attempts to reconcile them with propagation models represent a parallel effort to the reconciliation of bubble distributions to a hydrodynamic model that includes wave breaking and downward mixing and dissolution of bubbles (Vagle, Farmer & Deane, 2001).

Key individuals involved in the work:

D M Farmer is an acoustical oceanographer responsible for project design and analysis

S Vagle is an acoustical oceanographer responsible for implementation of acoustical systems, experimental execution and data analysis.

G Deane is an acoustical oceanographer at Scripps who is collaborating in the research including both field studies and acoustic analysis

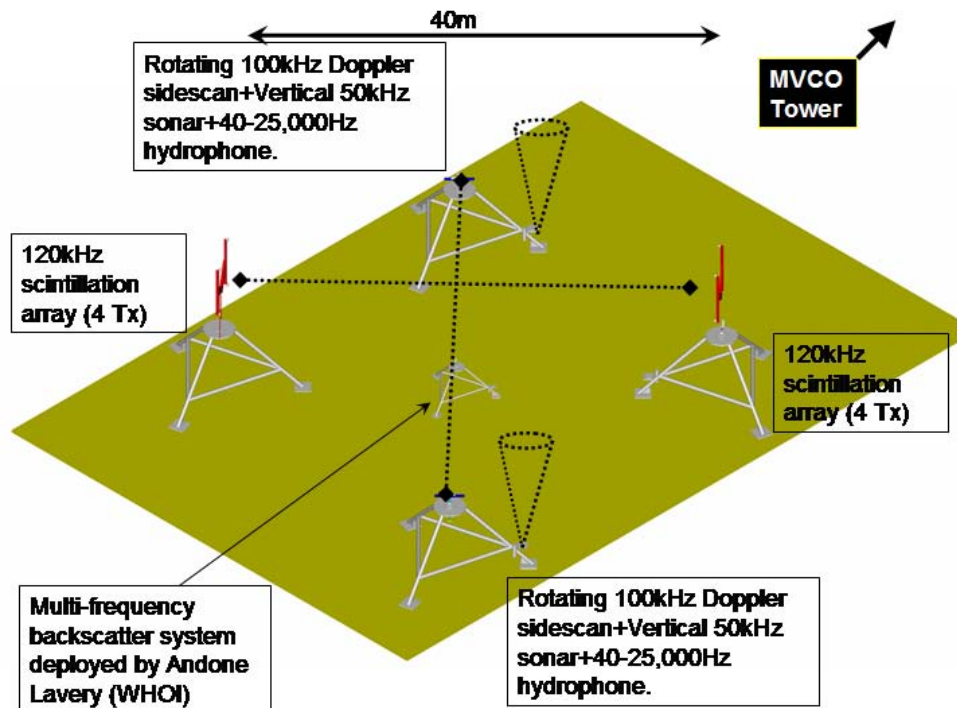
J Preisig is a researcher from Woods Hole who is collaborating in both field studies and data analysis and interpretation.

A Lavery is a researcher at Woods Hole who is interested in working with us on high frequency propagation and turbulence.

D Ullman is a researcher at the Graduate School of Oceanography, University of Rhode Island, with an interest in coastal circulation and shallow water processes.

## WORK COMPLETED

During the past year tests were carried out with the propagation instrument, both to



*Figure 2. Three dimensional diagram showing the location of the two 100 kHz sidescan sonar, and broadband hydrophone, tripods and the two 120kHz scintillation array tripods as they will be deployed on the seafloor acoustic Doppler Current Profiler (ADCP) and a Seabird 19plus CTD will also be deployed on one of the tripods.*

resolve problems that had arisen and to test optimal signal processing approaches. The tests revealed problems with one of the transducers and the cable link to shore. The software has been set up so that the instrument can be remotely controlled over the internet, and data can be downloaded remotely. Time series measurements were used to explore phase resolved signal analysis approaches.

The final configuration selected for the revised experiment is shown in Figure 2.

## RESULTS

The instrumentation has been tested in multiple deployments in Narragansett Bay. Data acquired includes horizontal propagation, back scatter Doppler sonar measurements from the surface and with azimuthally swept beams, video and other supporting data.

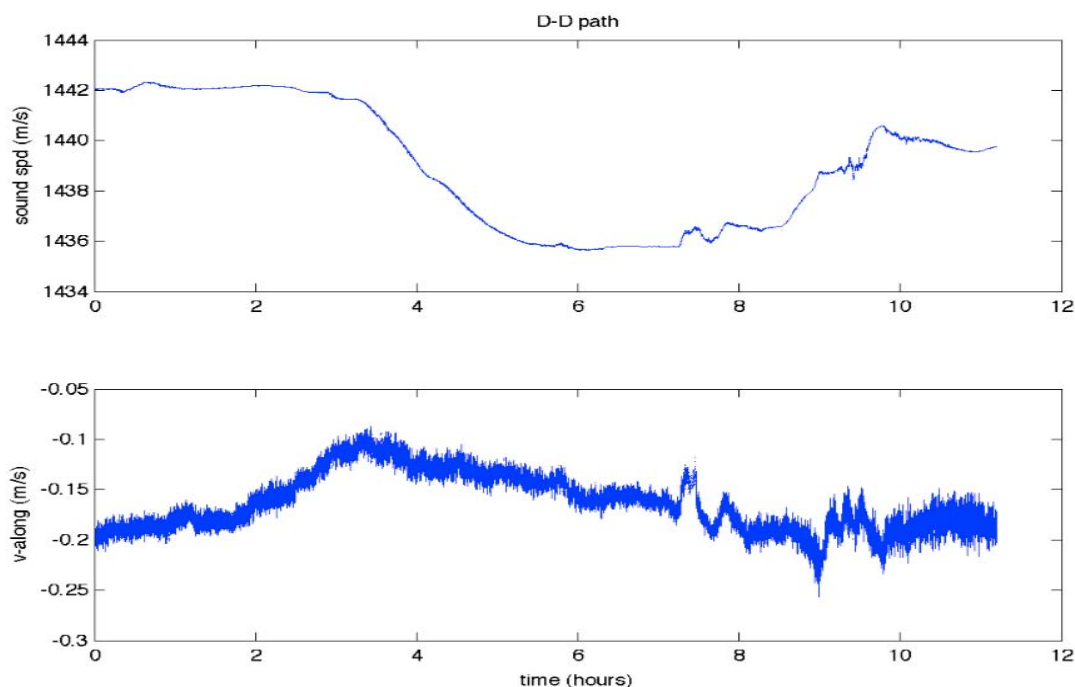
Figure 3 shows a representative 12h segment derived from horizontal propagation measurements; Figure 4 shows a representative pulse arrival times, illustrating the direct, surface and bottom bounce

returns. Pseudorandom coding was used and the resulting signals decomposed into time series of path averaged sound speed and resolved velocity component. These signals provide the input available for analysis of turbulence and other characteristics in addition to attenuation measurements that will be related to bubble observations. The reciprocal horizontal propagation transmissions have now been run for extended periods and reveal variability associated with changing sound speed and along path component of the flow speed associated with the tide. All the data are transmitted by cable to shore where they can be stored, and are also available as data streams over the internet.

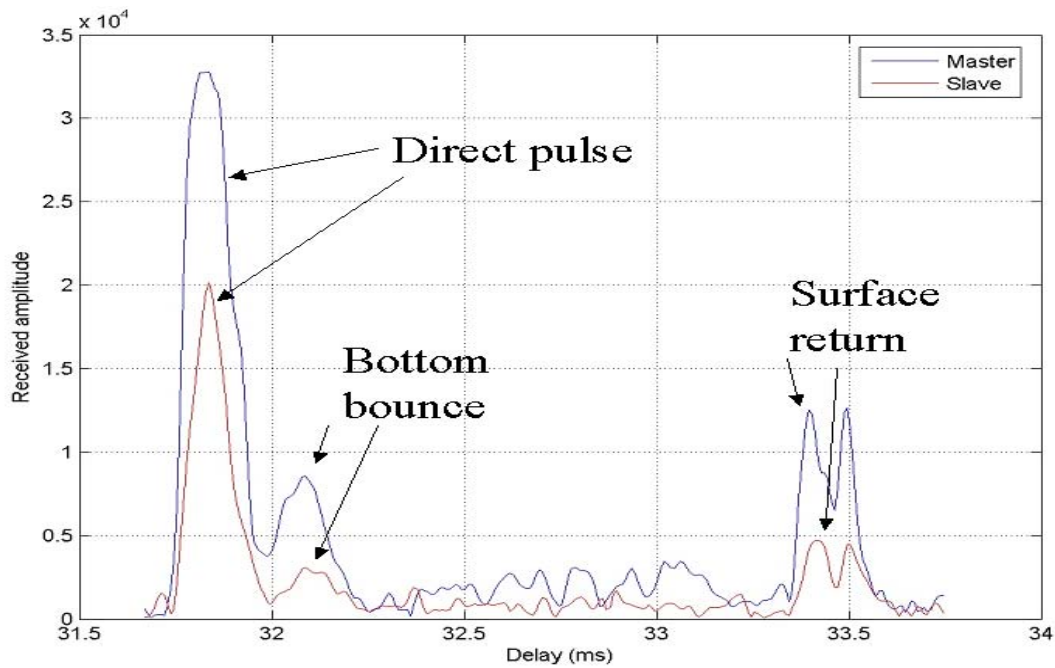
This past year we were able to continue with basic tests of simultaneous reciprocal transmission on all four transducers. This is an important step allowing us to separate scalar and vector components in the angle of arrival, with the potential of adding a new dimension to our propagation studies.

## IMPACT/APPLICATIONS

Considerations of the hydrodynamic impacts of the surface wave field, the bubbles and the turbulence are critical to the development of robust acoustical propagation models (Vagle, Farmer & Deane, 2001; Farmer, Deane & Vagle, 2001). The present studies and modeling efforts, combined with a revised experiment will improve our understanding of significant problems associated with sound propagation in the presence of bubbles and turbulence, especially as it applied to underwater acoustic communication. Analysis of the resonator performance, taking due account of reverberation effects, will provide added confidence in the use of this instrument in bubble measurements.



**Figure 3. 12h time series of path averaged sound speed and flow speed.**



**Figure 4. Sample signals, separating direct, bottom bounce and surface return.**

## RELATED PROJECTS

This project has now become closely associated with the MURI Topic #4 Underwater Acoustic Communications. The instrumentation and analysis supported under this proposal is being incorporated into the MURI project.

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